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TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 528

METAL CONSTRUCTION DEVELOPMENT

By H. J. Pollard

PART III

Workshop Practice

Strip Metal Construction - Wing Ribs

From Flight, June 21, July 19, Oct. 25, and Dec. 27, 1928

Washington
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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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PART III

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These articles have in the main had reference to strip construction of the structural members of airplanes. It is consequently appropriate that the following notes on workshop practice should begin with a description of one or two methods of forming sections.

Shaping of sections.- Rolling and drawing are common operations, and strip and sheet steel are frequently pressed to shape.

Different and possibly better methods than that given below could no doubt be described by others engaged in metal construction. The method, however, which we will survey briefly, has always given good results, and probably improvements on it will lie in the direction of speed of production. In experimental aircraft, or for that matter in quantity production of such volume as is to be anticipated during the next few years, the method indicated is likely to give the required production. For example, two rolling mills and drawbenches will produce from strip

*From Flight, June 21, July 19, Oct. 25, and Dec. 27, 1928.
(For Parts I and II, see N.A.C.A. Technical Memorandums Nos. 526 and 527.)

all the necessary sections for an output of five or six airplanes of average size per week.

The procedure is, in general, to do a certain amount of rolling on every section; in fact, where possible the completed section is formed by rolling. In cases where the finished section is bent to the equivalent of more than a semicircle as in Figure 8, major segment, (N.A.C.A. Technical Memorandum No. 526) or where spring-back necessitates the gap contour of the finishing tools having an arc greater than a semicircle, the rolls will be followed by a die fixed to the drawbench for the purpose of the second and subsequent operations.

Another method is to work dies in conjunction with rolls on the rolling mill, and so obtain the finished section at one pass; another way is to put the strip through a progressive series of dies, thus obtaining the finished section in one pass. A third method is to fit the drawbench with rolls and dies, and so obtain the finished section at one draw. The last-mentioned way, a combination of rolls and dies on a drawbench, might be the most suitable for mass production. Satisfactory results may be obtained with all the above methods. Whichever way is chosen, it is necessary that the cause or causes of troubles, if any, should be quickly diagnosed and remedied. If the principles of tool design and the procedure in forming the section are properly applied in every case, it is never a very difficult matter to detect and correct with certainty any irregularities

which may arise in production of new and unusual sections. Experience shows also that a final die can usually be either modified or completely remade much quicker than can a pair of rolls.

What is at present considered to be an excellent method of forming may well be found cumbersome at some time in the future, but changes in a system of working should not be made without ample reasons, as the adoption of new methods invariably causes delays in production.

In connection with this matter of forming I would refer to a remark appearing in N.A.C.A. Technical Memorandum No. 526, where it was stated in effect that the need for continuous heat treatment of steel strip was not apparent. The writer omitted to amplify this statement and say, "in the thicknesses of metal hitherto used in strip construction of primary members, and generally in cases where the steel in the heat-treated state has ductility adequate to the demands of the required sections."

Ordinary box spars, etc., have component parts rarely less in thickness than 0.012 in.; more often they have a thickness of 0.015 in., and in these cases two or three pairs of rolls, in the very worst cases four pairs and a die, are all that are necessary to form the strip. The section can be produced at the rate of 20 feet per minute or so, but as metal construction has developed so has the possible thickness of strip decreased from "thin" 28 G. steel until now, when material 0.005 in. thick and having S.40 properties is being used, it is no longer the

case that steel of 28 G. and thereabouts is regarded as very thin. It would appear that with the very thin material now available, the forming of hardened and tempered strip might with advantage give way to a combined method of heat treatment and forming, the strip being formed cold while in its softest state. For example, suppose a section as shown in Figure 1 were required, then if the steel ribbon were worked in the heat-treated state, the ultimate tensile strength being 80 tons per square inch, a series of tools having gap contours as shown in Figure 2, A, B, C and D, would be needed, but if the strip were supplied in the soft state, the ultimate tensile strength being, say, 30 tons per square inch, it might be possible to produce the section (Fig. 1), through a single tool or more probably through a pair of dies in tandem at one pass in continuous operation with the furnace. If the furnace were 4 ft. long the forming rate might be 3 ft. or 4 ft. per minute, the rate of absorption of heat for complete saturation and subsequent cooling being very rapid for this thin material. A modification to design, however, to Figure 3, would result in a substantial reduction of tools over section Figure 1 in forming from heat-treated strip. In a case where a section as shown in Figure 1 was required in quantities, however, there would be a very good case for the adoption of the continuous forming and heat-treatment method. For these reasons, and bearing in mind the possibility of the adoption of stainless steel strip in aircraft (which steel of

high tensile quality has not in general sufficient ductility for forming into sections in the finished heat-treated state), it appears to be likely that a continuous heat-treatment plant will form part of the equipment of every up-to-date aircraft building factory at some time in the future.

While the writer's arguments are not fortified by actual experience of the process, it would appear that, except in special cases, that soft forming and continuous heat treatment must be supplementary to the forming of strip which has already been heat-treated, because it must be cheaper to quench flat strip between flat water-cooled dies than to have special hollow dies for each of the many shaped members which make up an all-metal airplane. Again, the steel makers in supplying the whole of the aircraft industry with steel have large quantities of strip for treatment, and with the furnaces continually working the "setting-up" charges, etc., must be less than those which would be incurred by an aircraft building firm where the plant can only be used intermittently. With large quantities of strip on order or in sight the steel maker can install a large and suitable plant, including long furnaces, which make possible a quick rate of passing. This heat-treatment has to be paid for, and speaking generally, it does seem to be a more economic matter for the strip maker to perform this operation than the strip user.
Apart from costs, it seems more attractive to the strip user to be able to form his sections at speeds varying from 10 feet to

30 feet per minute than at speeds of as many inches per minute, with, in special cases, a limit of a few feet per minute. The fact that the important matter of inspection of the heat-treated strip falls on the steel maker, relieves the user of considerable labor.

These are questions of expediency. From the point of view of getting the lightest possible structure, there is a strong case for forming softened steel strip and heat-treating subsequently. In such a case, steel having high values of proof stress, say, 90 tons per square inch, might be used with advantage, and at the same time sharp radii may where necessary be included in the shape. Such sections could not be formed from strip already heat-treated to the above strength value. It seems likely for these and other reasons that both systems of forming may have their special spheres.

Returning to the question of forming heat-treated high-tensile steel strip by the method of rolling and drawing, the latter being a separate operation, the first step is to settle the shape of the final rolls or dies in order that the material may spring back to the designed shape. The formula generally used is

$$\frac{1}{R_o} - \frac{1}{R} = \frac{2f}{Et}$$

where R_o = the required radius of the portion of the roll or die gap curve under consideration;

R = the designed radius;

E = Young's modulus of the material;

t = the strip thickness;

and f = a figure dependent on the strength of the material.

The problem of spring-back is of extreme complexity, and the writer can give no mathematical justification for using this formula, but where f is taken as the ultimate tensile strength of the material, a fairly close approximation is obtained to the desired shape. If f is taken either as the elastic limit or the yield point, the material will certainly spring back far too much. As a matter of fact, the value given for f should be varied with the thickness of the material. In cases of very thin strip it is often found that the value of f for exact results exceeds the ultimate tensile strength of the material, also the spring-back is governed to an appreciable extent for any particular arc by the shape of the section at the extremities of the arc.

A typical variation in f with thickness is shown in Figure 4, and in Figure 5, the relation between R and R_0 is shown graphically for constant values of t and f; it will be noted that for very small radii the spring-back is small, but it is rarely negligible. The designer of the corrugated sections should also be responsible for the manufacture of the tools. Then by careful observation, and by having templates of finished sections made and taking measurements of these, he will quickly collect data enabling him to obtain results with all the preci-

sion that is necessary for this work. If the material is over-size, or where considerable variation of strength occurs along the length of a strip, irregularities will ensue in the formed section. The technique of the manufacture of heat-treated steel strip has greatly improved during the last 18 months or two years, so that now trouble due to either of these causes is of rare occurrence. Where reduction in thickness of strip is brought about between rolls, or in a die due to either faulty tools or over-size strip, then bad forming results will be obtained. It is not desired to give the impression that the production of corrugated strip is an extremely difficult or fortuitous matter. On the contrary, it is an operation in metal construction which, given the proper conditions, causes very little trouble.

Having determined the shape of the finishing tools, the selection of the different stages from the flat strip to the final tool is a matter entirely for experience; the only considerations are to produce the section with the minimum of rolls or dies, at the same time ensuring that no damage is done to the strip through endeavoring to perform too much work at any particular stage.

Figures 6 A, B and C, 7 A, B, C and D, and 8 A, B, C, D and E are typical examples of progressive tool contours.

In general, it is not necessary to have different rolls for different thicknesses of strip for the same section, but the

final die must, of course, be different for different thicknesses, in order to get the correct final shape. Thus, in Figure 7, two pairs of rolls are adequate for strip ranging from 28 G to 24 G in thickness, but a different die is necessary for each gauge. When the finished shape is produced in rolls, then the final pair must be designed for each strip thickness in order to correct the spring-back, which varies inversely as the thickness.

Until the tool designer has had a fair amount of experience, it is better to over-estimate the amount of spring-back which is likely to take place than underestimate it, for the operation of increasing the width of a formed section is a much simpler one than making a wide section narrow. In the use of rolls the parts of the section where most work is to be done should be as near as possible to the line midway between the axes of the rolls. The section designer should always endeavor to include one or more bends of small radius in the sections he designs, and these sharp curves should be formed as much as possible in the first pair of rolls. The groove thus formed will act as a guide for the strip through the subsequent rolls or dies. Experience has shown that it is more satisfactory to do some work on <u>every</u> part of the width of the strip at each stage and <u>not</u> to complete one arc before beginning to form another. (It does not follow that this would be the better procedure where other methods of forming are to be followed, as for instance, feeding through rolls and dies at one pass.)

Templates need to be made with great accuracy, and trouble is invited by attempting short cuts in making them. It is essential that the templates should be fitted to a replica of a section of the required roll or die. These copies of the tool contour (usually known as "master templates" or "proofs") as well as the shop templates are usually made from 18 G sheet steel. Each proof and its template must be reversible in the case of symmetrical sections, otherwise special markings are needed on the rolls as to which ends are to be threaded on to the rolling mill spindles: this should not be necessary. Fitting the proofs together gives the true contour and gap, and this must agree with the calculated shape. After the rolls or dies are made to the templates and the rolls are bored, broached, etc., it is usual to try them out before hardening, and it is usually necessary to touch them up here and there where the material shows signs of being nipped: this is a matter for ordinary observation. It is always easier to form a symmetrical than an unsymmetrical section. Unsymmetrical sections are rarely required, but when they are, some ingenuity may be required from the operator because of the possibility of the strip being fed through the rolls at varying speeds across its width. Figure 6, A, B and C, is a case of an unsymmetrical section.

Rolls should be made from good case-hardening steel; ordinary mild steel is often used, but a 0.1 per cent nickel steel is better. Although a glass hard surface is not necessary, yet

the harder the surface the better, since there is always a tendency for the edges of the strip to cut furrows in the sides of the rolls and in time such grooves may tend to throw the strip out of line. Owing to the large mass of metal that is sometimes necessary in a roll, it is not always easy to obtain a hard surface without some distortion after case hardening. The only operations after hardening should be polishing and grinding out the bore. Oil lubrication is, of course, an advantage in rolling and a very liberal supply of oil is an absolute necessity in drawing.

Die making is quite a different matter from roll making. Where only a small quantity of a section is required, ordinary cast-iron dies may be used, but the gap will be good only for a few hundred feet of strip. Indeed, for soft metals a simple wooden die can be made. For quantity production in steel it is usual to make the body of the die in cast iron, the lead-out portion being fitted with a hard steel face. Owing to the harsh nature of the drawing operation, this exit face should be glass hard, or rapid wear will take place and frequent renewal will be necessary. A sketch of a typical die is shown in Figure 9. Special devices are frequently necessary for use with dies, such, for instance, as floating mandrils for forming complete curls, etc. There is usually no difficulty in fitting these to the dies. While drawing cannot compare with rolling in speed of production (except where the material is pulled through rolls) yet

where an experimental section is required urgently, drawing may be resorted to in preference to rolling, as dies can be produced more quickly than rolls. For this reason also it is often more economical to make dies where only a small quantity of the section is likely to be required.

If, for instance, a figure, as shown in Figure 10, were required urgently in a special case, tools for shaping, as shown in Figures 11A and 11B could be made

Apart from selecting appropriate stages for forming process, the only other consideration of first importance lies in keeping the length of arc constant for each curve from stage to stage, as in Figures 8A, 8B, and 8C, Part A $r_2\ \alpha_1 = r_2\ \alpha_2 = r_3\ \alpha_3$, etc.

Various artifices need to be introduced occasionally. For example, in members subjected to low values of stress intensity, arcs having large values of R/t may be used, and it is often better to have a surface composed of one large arc terminated by a small radius than a surface composed of a series of flats joined together by arcs of small radii. In the case of the arc of large radius, it will be found sometimes that the extremities of the calculated contour overlap, thus giving an impossible shape for a die. For example, if parts of cross section (Fig. 12) were required, then the first operation of rolling could be performed with the rolls, Figures 13A and B, correct angles and radii for the spring-back give the shape shown in Figure 14. In a case like this, a certain amount of bending may be done along part of the arc, as shown in Figure 15, portion x. Then allow-

ing this to spring back, to bend a further portion (y) of the arc as shown in Figure 16. Thus is the required shape obtained. The same process is necessary in working extremely thin strip. The above cases provide on their own account very good arguments for continuous heat treatment. Sections of this contour, however, are not required in large quantities.

On the drawings giving the stages of forming, the centers from which the various radii are struck should be specified in relation to two axes at right angles, as indicated in Figure 7A. Such centers are readily found by calculation and otherwise, and these dimensions are of great service to the template makers, and should be used as a check on the layout of the contours.

In new designs of members, close cooperation between shops and drafting room can often save much unnecessary labor. For example, suppose a spar has been designed having over-all dimensions 4 in. by 2 in., and suppose that when the first sample or test specimen of spar is made up, the over-all dimensions are 3 15/16 in. by 2 1/16 in., then if the spar produced withstands its specified test load, and it is known that spars of these dimensions and having the same uniform material can always be produced, it is obviously easier and cheaper to modify the design than to remake the tools to produce the original spar section to the calculated dimensions.

It is true that minor difficulties will appear in the early stages of this work. One of the most common is for the edges of a formed strip to buckle as they emerge from a die or pair of

rolls or to take a sinuous form: this is nearly always due to the strip being wrongly fed into the tool, causing a stretching of the material at the edges. By altering the method of lead-in this trouble can usually be overcome. As illustrating this, if we have a rectangular piece of paper held so that one end is in the form of a circle, the other end being left flat, and then an attempt is made to deform the sheet so that the end curve will lie in a plane at right angles to the center line of the paper, then the long edges will tend to tear. If this were steel strip, and the die gap was of similar shape to the curved end of the paper, then the strip would have to be fed in so that the edges could follow the natural curve indicated by the paper, otherwise the edges would stretch and finally wave.

The reader may think that the forming of section from strip becomes easier with softer material: within limits, this is so, but the successful forming of very soft materials is often far more difficult than corrugating steel of S.40 standard; for example, in one case, four pairs of rolls were required to produce a certain section from material of proof stress 18 tons per square inch, and only two pairs when the proof stress was 70 tons per square inch, the gauges being the same in each case, but that was simply because the soft material could not withstand the work of deformation on two pairs of rolls without buckling and it had to be done by more gradual stages.

It is clear from the foregoing considerations that this

matter of corrugating and section forming is a subject that teems with interest in both its theoretical and practical aspects.

We now pass on to the assembly of these sections into structural members, and as a beginning deal with the building-up of wing or stabilizer spars of the parallel box variety. It has been previously stated that owing to the existing small demand for aircraft, and to the constant changes in design, automatic machinery for the assembly of spars and similar members is at present out of the question, but sufficiently rapid production for present-day requirements has been obtained, in the case of the above-mentioned members, by such methods as are described below.

Figure 17 shows a gang press equipped with a tool A, which pierces eight holes in the lips of spars, two in each of the four edges, and a tool B clinches the rivets which are put into place by hand in the clear space between the two tools. Both tools are actuated by one stroke of the press. The spar is carried along on bar C; there are holes in this bar spaced 2-inch pitch, and it is moved along by means of lever D, the spring-loaded plunger E ensuring that the spar is moved along exactly 2 inches. The punching tool follows straightforward lines, and little need be said about it beyond the fact that it is very important to ensure that the small "punchings" are carried away effectively from the tool; this may not, in all cases, be a very easy matter.

The clinching tool is rather more complicated. The "holding-up" portions must clearly come to rest under the heads of the eight rivets before the "up-setting" portion comes in contact with the rivet shanks. How this may be brought about is shown in Figure 18, which is a section of the tool showing the spar in place; in order to give clearness to the explanation, the right-hand half of the sketch illustrates the position of the movable portions of the tool when the ram is at the top of its stroke, and the left-hand half their positions at the end of a down stroke.

F is the plug for attachment to the press crosshead. This plug is screwed into arm G. Downward movement of arm G causes links H_1 to rotate round pins I, the other end of the links giving a rectilinear motion to part J. This part slides in grooves machined in the body of the tool. To each pin N securing links H_1 to cam J is attached a link H_2. These links give vertical motion to the lower arm G_1. The sliding cam gives the correct motion to the rivet head support holders K. The sequence of motions can be plainly followed from the drawings. The curved ends of the cams come first into contact with the sloping end of the "holding-up" tools; during the first part of the stroke the upper and lower "holding-up" tools are forced apart until the "sets" come in contact with the rivet heads; provision is made, of course, against any endwise or lateral movement of the parts K. When the parts K are in position

shown on the left-hand half of Figure 18, the curved end of J is no longer in contact with the sloping end face of K and for the remainder of the stroke the horizontal faces of J and K are alone in contact; therefore, no further vertical movements are given to parts K, but during the period these parts are in horizontal sliding contact arms G and G_1 are each still moving towards the center of the tool by reason of the downward movement of the ram crosshead and links H_1 and H_2, as previously explained. These horizontal arms carry the "snaps" M. It is thus clearly seen how the correct motions are given to the eight holding-up punches O and the eight head-forming punches M. Only four such pairs of tools are to be seen in Figure 18, but on the actual machine there are four more pairs, each at 1-inch pitch from those shown. On the up stroke, springs P bring holders K back to the position shown in right-hand half of the drawing.

The punching tool is not so complicated as the riveting tool, as there is obviously no need to give motion to the die, only the punches need to be operated.

The mechanical operations in spar assembly using this combination of appliances are therefore:

(1) Depress plunger E.

(2) Rotate the lever D, and after slight movement of the bar C, leave go E, and after the bar has traveled 2 inches the plunger will automatically register with the next hole in C.

(3) Give the press ram the requisite down and up movement.

If the inner vertical faces of the tools A and B are a little more than 6 inches apart, the above three operations may be repeated three times successively; then if the pitch of the rivets is 1 inch as in this particular case, it will be necessary before the operations are continued to place the necessary rivets in the holes which are in that part of the spar lying between the two tools. This has to be done by hand, but with simple spring loaders the whole six on any particular lip may be fed in simultaneously. It will be noted in Figure 18 that the upper rivets are put in upside down. In order to prevent them falling out, a thin layer of grease is spread on the under side of the two upper edges. The quickest results are obtained by two operators, one actuating the parts D, E, and the press handle and the other merely filling the loaders with rivets.

The above compound process could be extended so that more than eight holes could be punched simultaneously or eight rivets clinched if desired.

There are other advantages in this method of spar assembly. One is that manufacture in such a way does not call for specially skilled operatives, while a second advantage is that equal work is being done on each of the edges simultaneously, thus, there is no tendency for the spar to twist or bend. In earlier methods of assembly, where work was done on each rivet and edge separately, considerable skill was called for on the part of

the operator in riveting up, rivets having to be put in and "snapped" with discrimination. Taking an extreme case as an illustration, it will readily be seen that if one of the four edges only is riveted up completely along its length, the stretching of the metal round each hole which accompanies the closing of the rivets will cause that edge to become curved, and thus throw the whole spar out of line.

In the manufacture of strip fuselage bracing members, as illustrated in Figure 9 (N.A.C.A. Technical Memorandum No. 526), a similar tool may be used under a gang press (see Fig. 19). The component tools are, of course, much simpler in this case because of the simpler form of the product required.

In some structural members there are not two axes of symmetry; in those cases the operations causing stretching of the edges cannot be carried out in such a way that one tendency to cause distortion cancels out with another. A case of this kind is illustrated by the fuselage longeron (Fig. 20).

A procedure which may be followed in such a case is to place the component sections in a jig so that the axes of all sections YY are vertical and the axes XX do not lie in one plane, but the points of intersection of the axes lie on a curve which is concave upwards. Then, when the rivets are placed in the lips ll the stretching effect is such that when the member is riveted up and removed from the jig the longitudinal axis is straight.

Such a procedure, it is admitted, is not consistent with the quickest production, and it has been found that with high-tensile steels and suitable choice of rivets and rivet spacing the distortion in assembly can be reduced to a small amount which can easily be corrected by bending back to the straight again. An idea of the amount of the initial set that may be required in some special cases may be gained from Figure 21. The tools necessary for assembling these members are shown in Figure 21, one for punching, the other for rivet-clinching.

The shape of some built-up members ensures that there shall be no deformation after riveting. Some interplane struts furnish an example of this. The load-carrying portion of such a member is shown in the jig (Fig. 22). By virtue of their depth these members have sufficient strength to resist the bending tendency of the riveting-up operation, and a straight assembly jig may be used. The illustration shows the details, and the method of using the jig needs little description. The flange and web are held in position by means of straps Q, and the hard bushes are carried in movable drill jig R. In this case the holes are drilled by means of an air-driven tool. There are advantages in using these air drills, the chief one being that the speed can be regulated easily over a wide range. In assembly, punching holes is nearly always preferable to drilling, but there are, unfortunately, some cases where the positions of holes are not accessible for punching.

The horizontal studs S are used for holding the drilling jig R. This is moved into an adjoining position after the drilling of each set of eight holes.

It is not claimed that the above methods of assembly would be adequate for large-scale production, but such production would warrant the spending of a larger sum of money in tools than is indicated by the appliances described. The amount of money that may be spent in tools preparing for a job should bear some proportionate relation to the number of parts required; Figure 22, for instance, merely shows a simple but effective jig suitable for the requirements of the moment.

Wing Ribs

As to rib manufacture, Figures 7A, B, C, D illustrate a method which has been practiced. Figure 7A shows how channel booms may be formed to any desired contour: the small roll U is capable of adjustment up and down by means of wheel V, and the channel is moved backwards and forwards in the pair of rolls which are actuated by the handle through gear wheels.

Figure 7B shows the method used for folding over the sides of the bracing channel. The end of the channel is held in the small clamp W and this clamp is held by a pin through a hole in the angle iron. This pin is inserted successively in the series of holes shown in the sides of the angle. After each "setting" the handles X are turned over, this action folds

over the sides of the channel which lies in a groove between these handles.

Figure 7C shows how the continuous bracing channel is bent to the required shape: small clamps are suitably spaced on a base-plate and the channel is simply bent round each clamp. A cam is rotated by means of handles Y, thus firmly grasping each portion of the channel. The booms and bracing so formed are placed in the assembly jig 7D and by means of air drills the necessary rivet holes made through boom and bracing together. This assembly jig consists of upper and lower rectangular sectioned steel bent to the requisite contour and screwed to a base-plate. The hard bushes are carried in swivelling blocks; after drilling, these blocks can be swung away from the boom and the rivets inserted and clinched, thus completing the manufacture of the rib.

Repair of these members after damage is a very simple matter provided that the damage is not such as to need the replacement of the whole component; a bent rib boom that cannot be efficiently straightened may have another channel placed over it, the internal dimensions of which are slightly greater than the external dimensions of the original boom. Similarly with the bracings; but since all rivets are easily accessible, the insertion of a new piece of rib bracing is an easy matter, as also is the replacement of a complete rib boom, if this is considered necessary.

Again, with spars and longerons repairs can be easily effected in these components by virtue of the wide riveting edges. These have purposely been kept as wide as possible (Figs. 10 and 11, N.A.C.A. Technical Memorandum No. 527), so that in the case of spars, channels may be placed in the webs along the damaged portion and the shallow sides of these channels attached to the riveting edges of the spars as in Figure 11 (N.A.C.A. Technical Memorandum No. 527), but in this case this shallow channel would have no holes drilled in the base, as indicated in figure referred to. If it is preferred, lengths of flange or web may be placed over the damaged portion of the spar and secured only to the riveting edges of the member, but generally for spars buckled in the flange and web a relatively heavy gauge (say, 16 G) flat-based channel, secured to the ribs of the member only, is sufficient. At a risk of repetition of what has been said previously, it is again emphasized that this kind of repair may be readily done externally on the spar without any interior attachment.

Regarding damaged spars, it may be said at this stage that local buckling of a spar flange (caused, say, by a wing tip striking an obstacle or the ground) does not necessarily mean that the airplane must be dismantled and taken back to the airport by road or rail. A spar loaded in the manner indicated in Figure 5 (N.A.C.A. Technical Memorandum No. 527), until the compression flange buckles would most probably on a re-test still support half or even three-quarters of the total load carried

during the first test and a spar similarly buckled would consequently be safe for a cross-country flight. A more serious matter might be the deformation of the whole wing and the consequent alteration to its aerodynamic properties. In the event of part of a spar being fractured, particularly in the tension flange, repair or replacement would be imperative before the airplane could be used.

As regards fuselage members, longerons and struts, if the major portion of a longeron is damaged (dented) a patch of section and gauge identical with that originally used may be sprung in place and riveted to the two lips. It is, of course, necessary to allow the patch to extend a few inches on either side of the dent. Such a repair is shown in Figure 24.

Since metal construction development has been mainly in service aircraft, this matter of repair has necessarily been kept well to the fore. In commercial aircraft the need for repair, that is, repair to a damaged structure, should be negligible compared with possible damage to military airplanes; nevertheless, experience has shown that facility for repair in a member can quite well be included in the design without serious sacrifice of either weight or developed strength, and there is reason to believe that in future constructions or higher developments of the art of metal construction, efficiency of members and ease of repair will, in good design, continue to be complementary characteristics.

For Part IV, see N.A.C.A. Technical Memorandum No. 529, which follows.

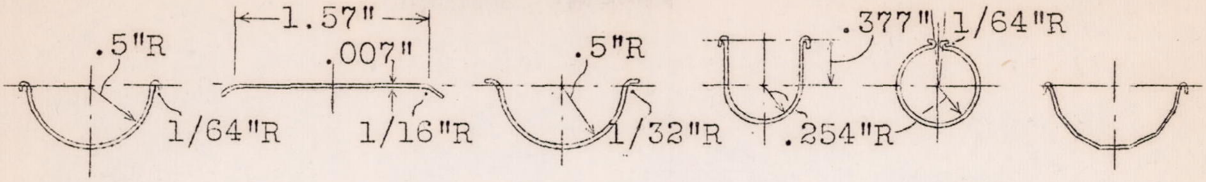
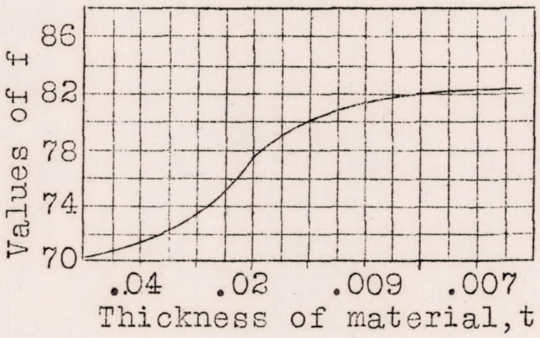
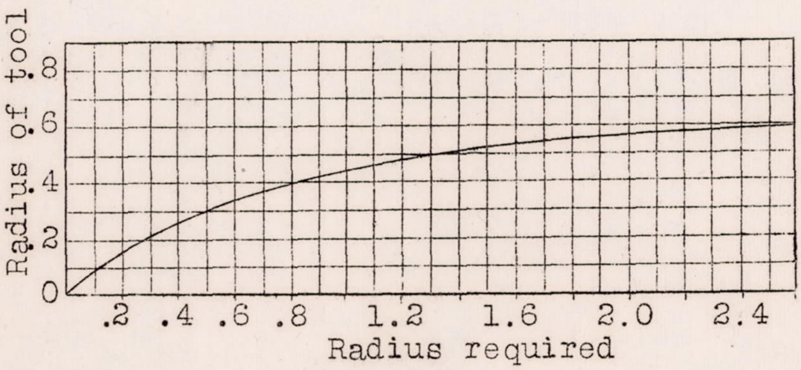


Fig.1 Fig.2A Fig.2B Fig.2C Fig.2D Fig.3



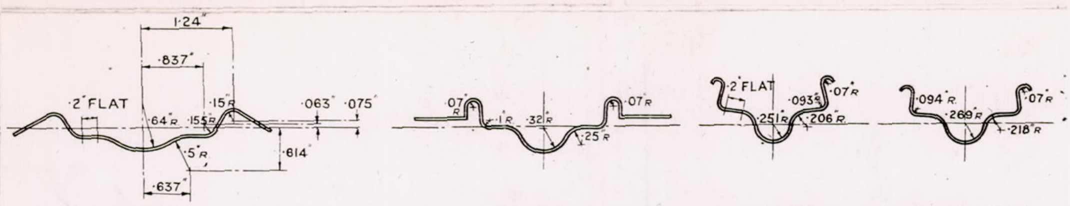
Graph indicating the degree of variation in the value of f with t.

Fig.4

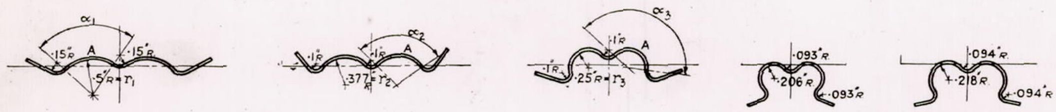


Graph showing relation between R & R_o for t=.01 f= 80 E= 12500

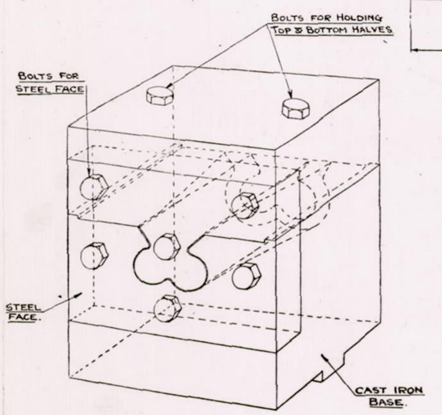
Fig.5



7A. ROLL. 7B. ROLL. 7C. DIE FOR 28G. MATERIAL. 7D. DIE FOR 24G. MATERIAL.



8A. 8B. 8C. 8D. DIE FOR 28G. MATERIAL. 8E. DIE FOR 24G. MATERIAL.



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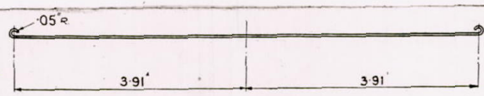
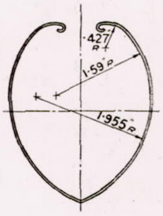
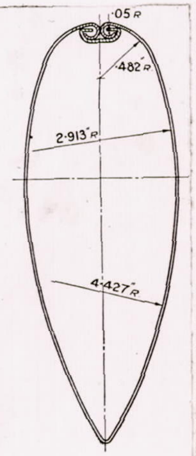


11A.



11B.



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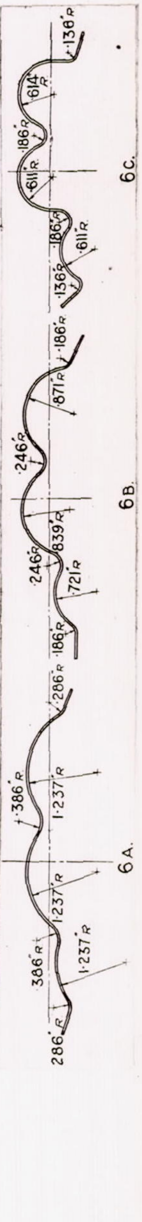
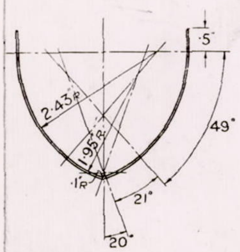


6A. 6B. 6C.



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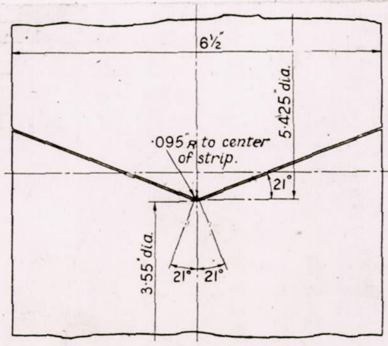
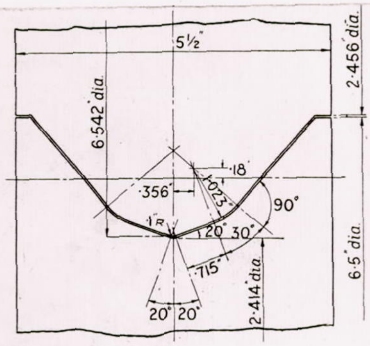


13A



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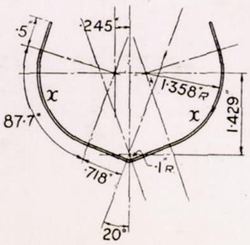
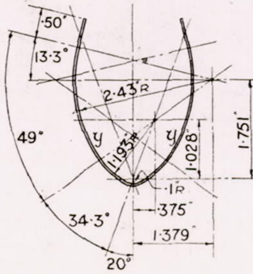


15



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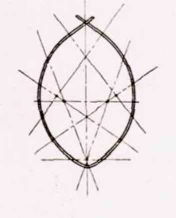

14.

13113 A.S.

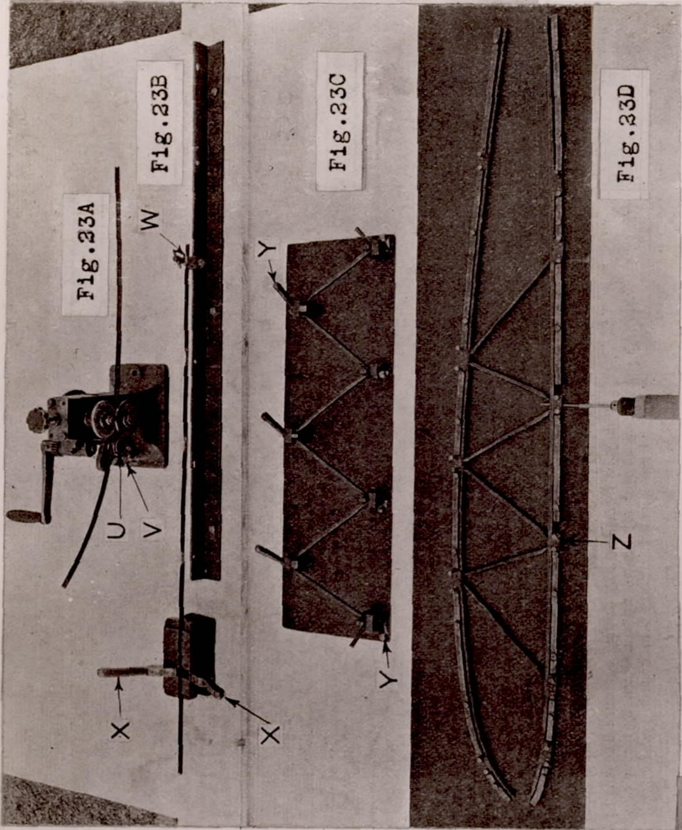

Fig.23A

Fig.23B

Fig.23C

Fig.23D

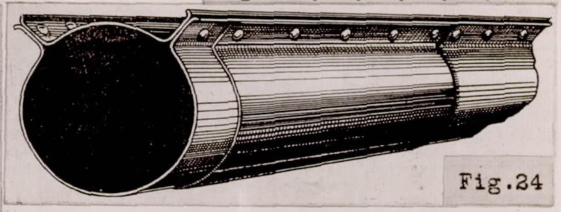

Fig.24

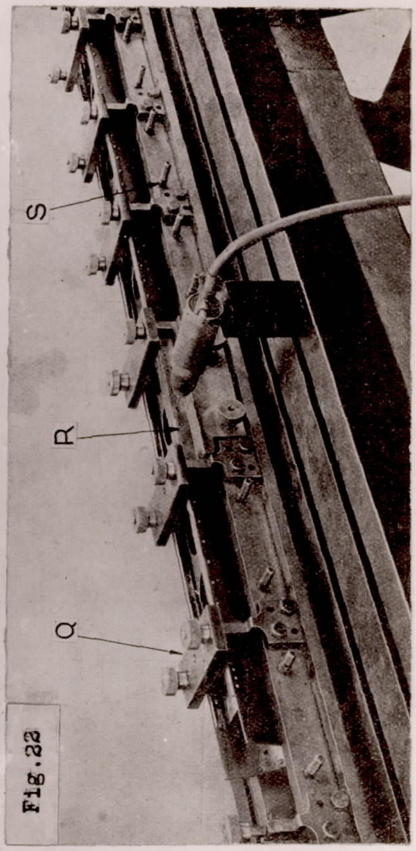

Fig.22

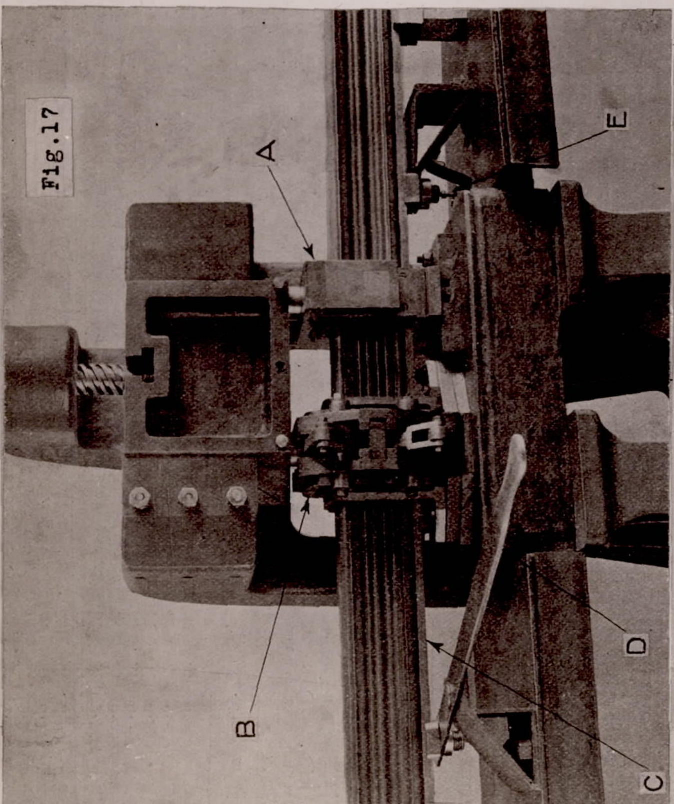

Fig.17

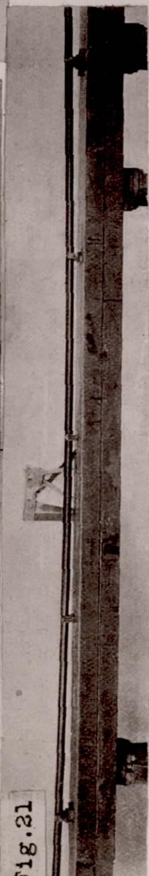

Fig.21

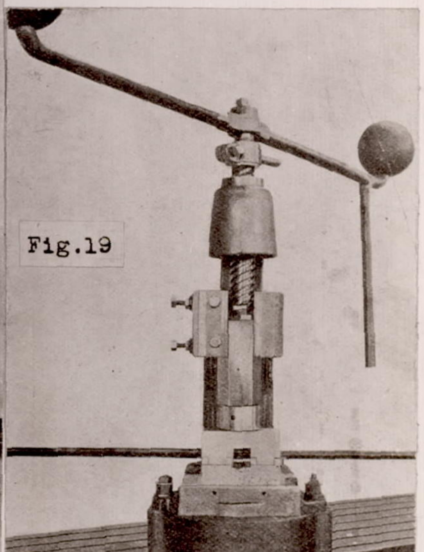

Fig.19

13114 A.S.

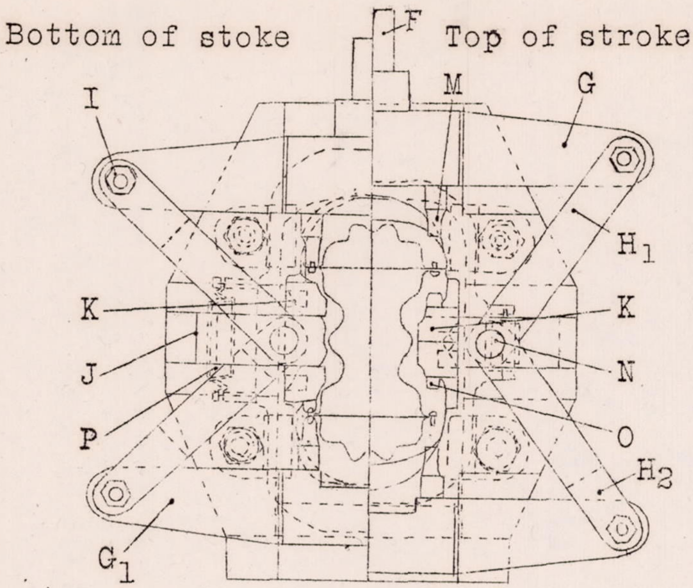

Fig.18

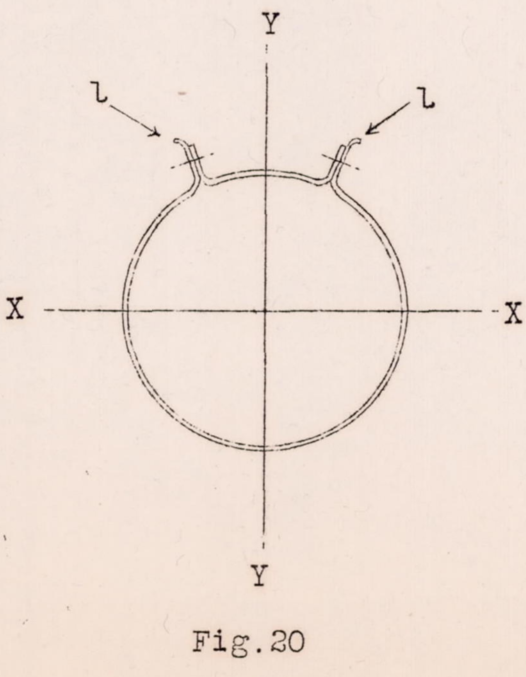

Fig.20